Status of the CDX-U liquid lithium limiter experiments

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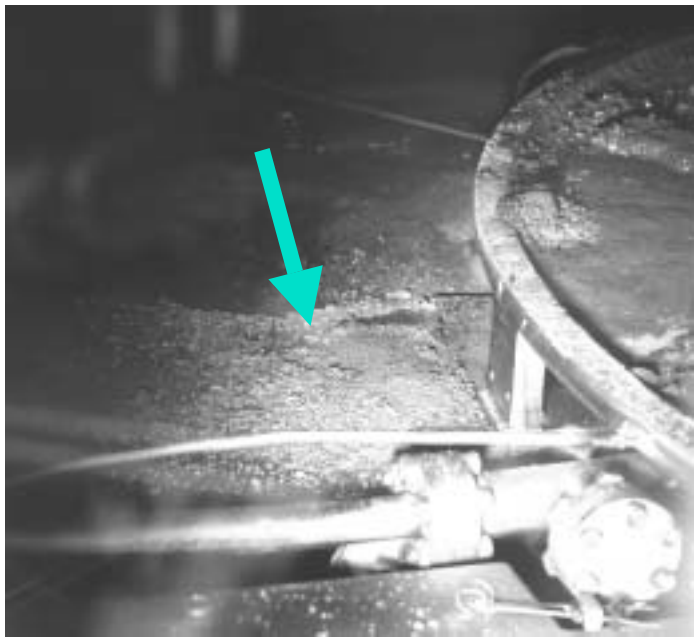
Operational Summary (since spring meeting)

- CDX-U was vented over the summer and the vessel interior cleaned
- Toroidal tray was removed and successfully cleaned
  - Original tray has been reused; spare tray held in reserve
- Heat shielding for lower vacuum windows augmented
  - Required for 500^{o}C operation (UCSD criterion)
- Additional cooling of o-ring seals, added heater power
- Vessel was pumped and leak checked
- Tray has been heated to 500-540^{o}C (minimum)
  - Only in vacuum so far. Tray filling procedure will require argon backfill.
- Present tasks include additional cooling
  - Bracing of TF coils
- Baseline plasma shots with empty tray

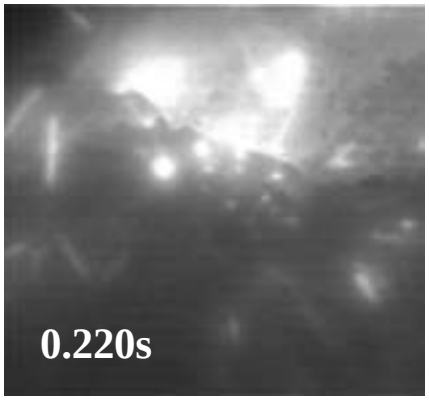
"Halo" currents are the biggest problem for liquid metal PFCs

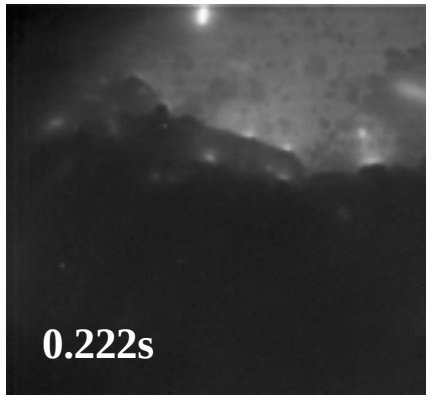


⇒ Currents which close *in the plasma*

- Very active unipolar arcing seen during early plasma operations at these sites
  - Lithium particulate ejected from the tray by **J×B** forces during arc.
- Arcing subsided as the tray cleaned up.
  - But not completely.

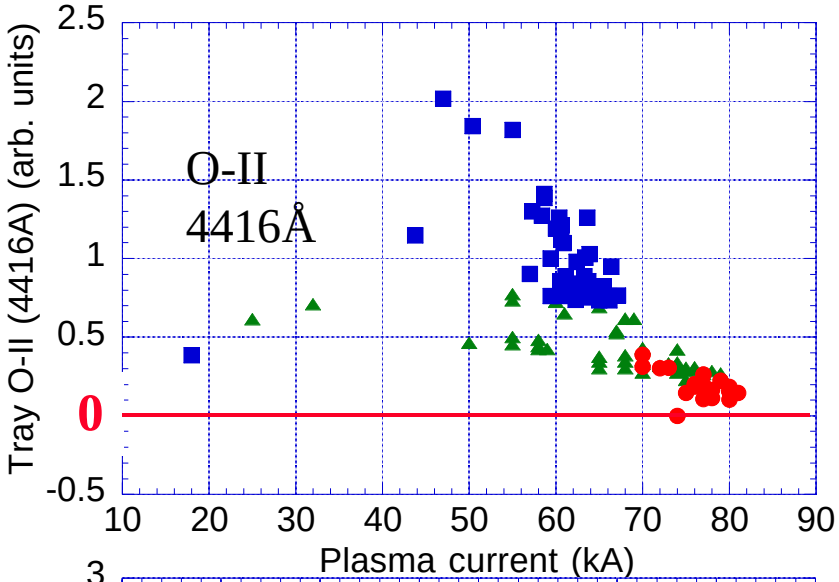
⇨Stills of plasma-lithium interactions in Li I light at 6708 Å; 1000 fps, 1/5000 s shutter speed

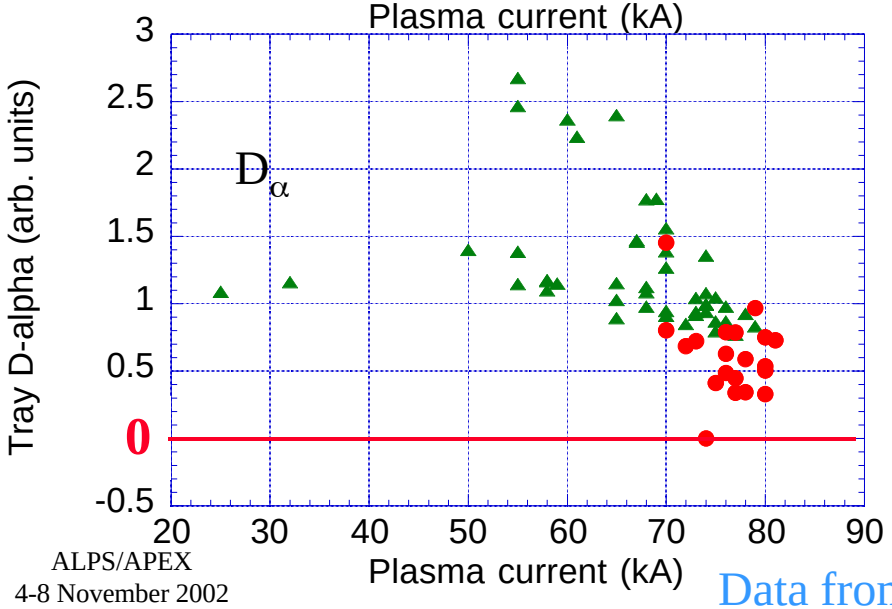




Lithium improved plasma performance in CDX-U

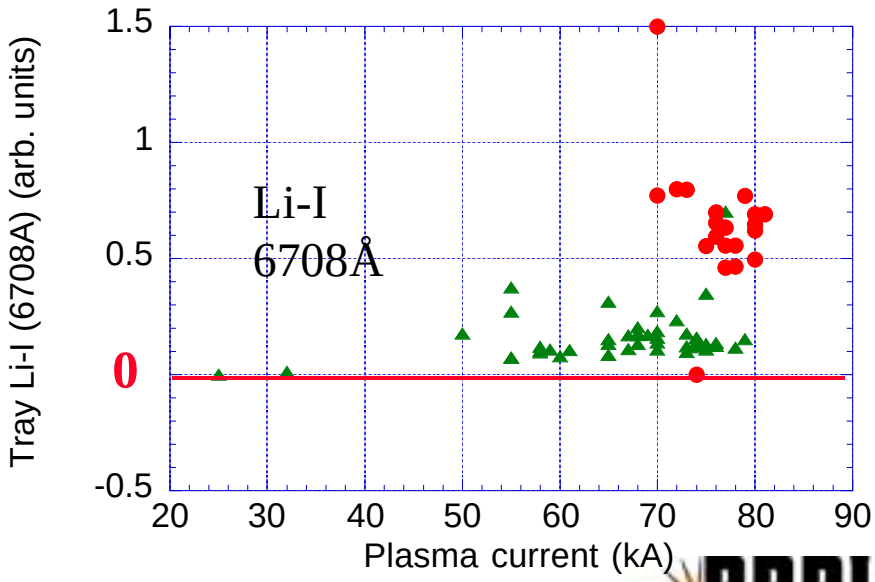
Local improvements with lithium





- Least oxygen, D_α light for liquid lithium
- Most lithium light for liquid lithium

● Liquid lithium in tray (250° C)
▲ Cold lithium in tray
■ Bare stainless steel tray



Data from the ORNL tray filterscope

Global radiated power is slightly reduced for discharges limited on liquid lithium

- Data from Johns Hopkins tangential bolometer

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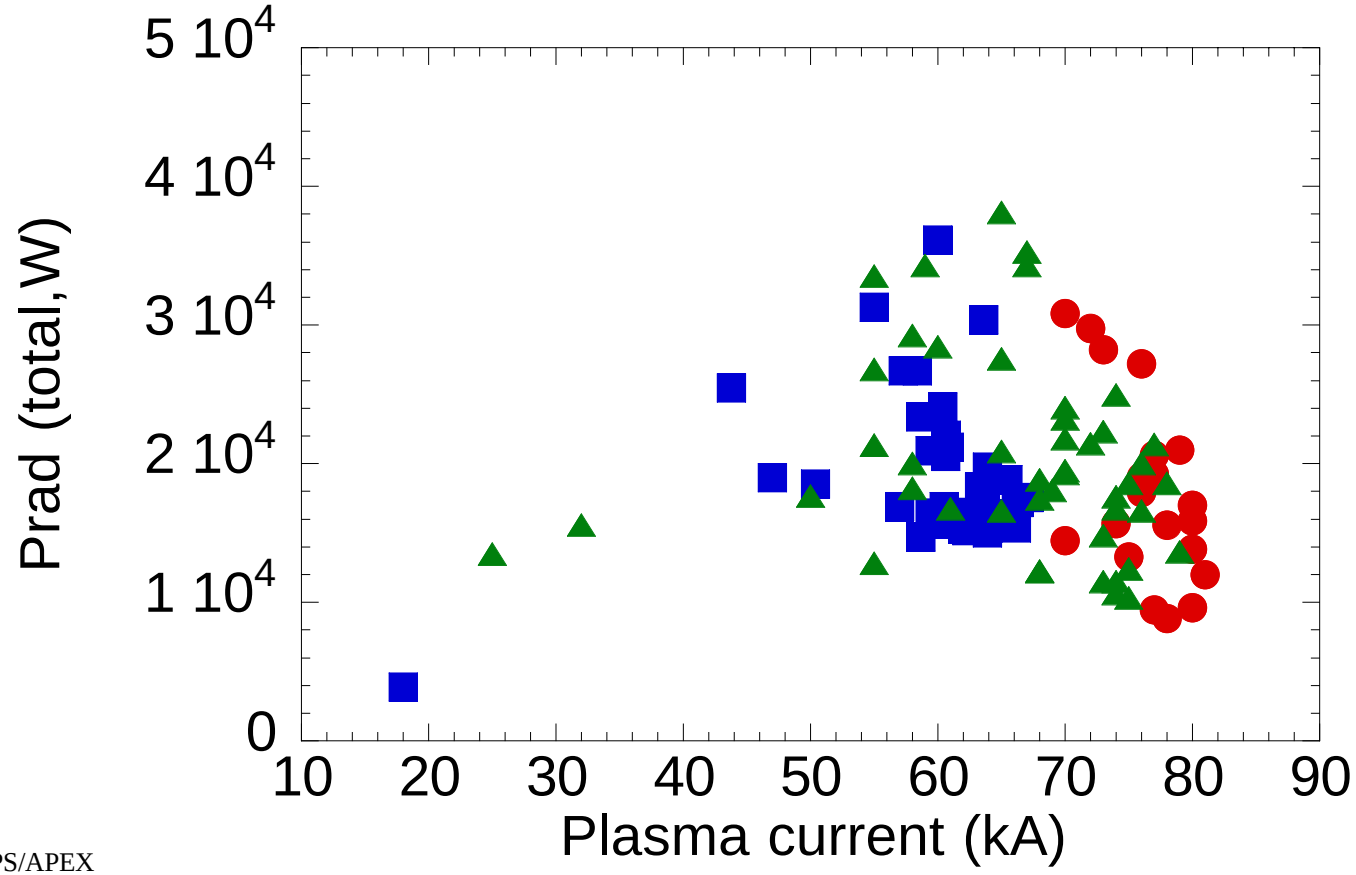
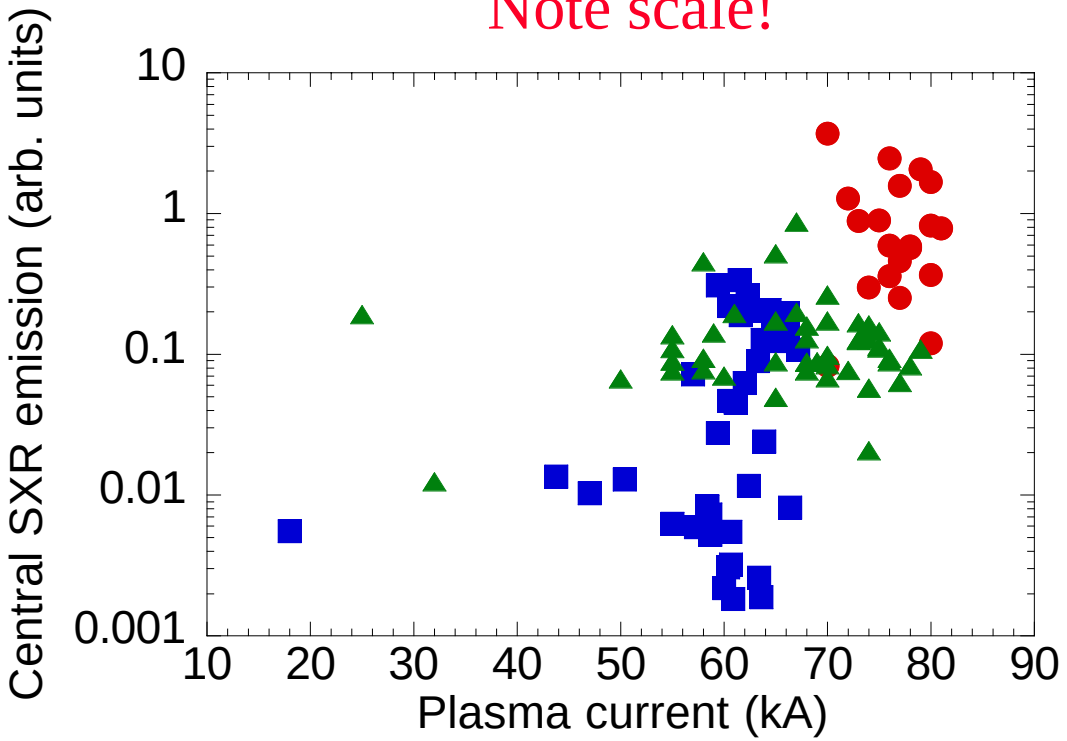
▲ Cold lithium in tray
■ Bare stainless steel tray

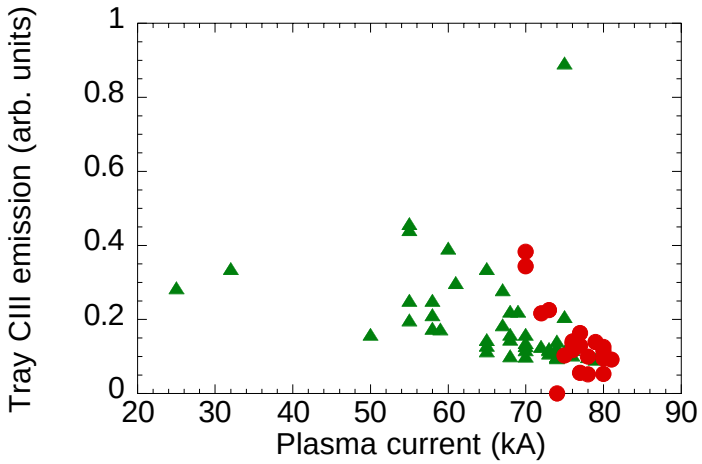


Central soft x-ray emission indicates that plasmas limited on liquid lithium have higher core T_e

Note scale!



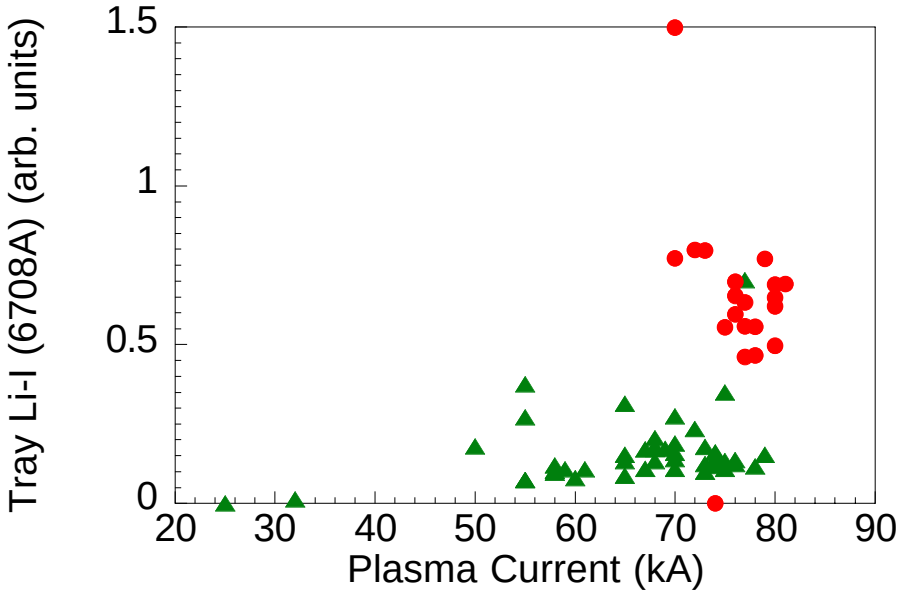
- Edge carbon emission indicates that rise in emission is not due to a carbon influx

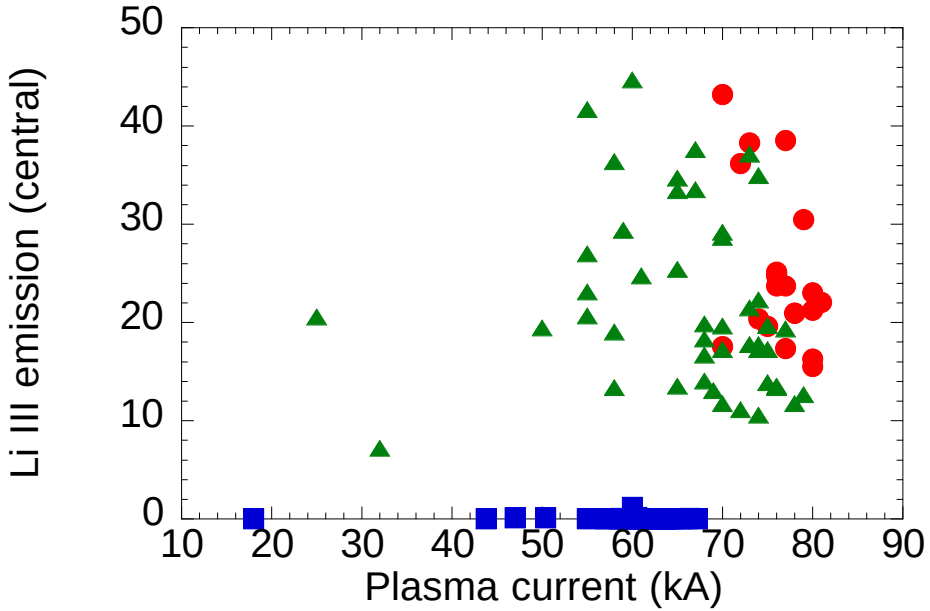


● Liquid lithium in tray (250° C)
▲ Cold lithium in tray
■ Bare stainless steel tray

Edge, core lithium spectroscopy indicate some lithium influx

- Core lithium concentration does not increase with liquid lithium operation, compared to the solid.
  ⇒ Core T_e measurements needed to confirm

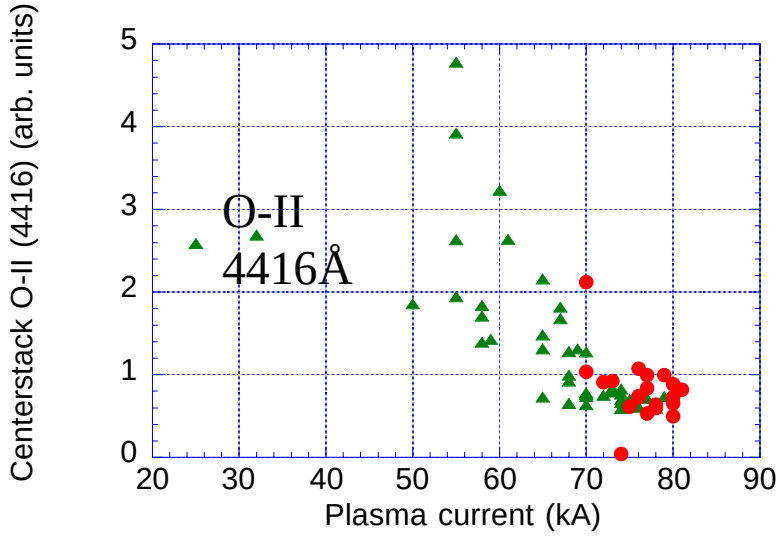


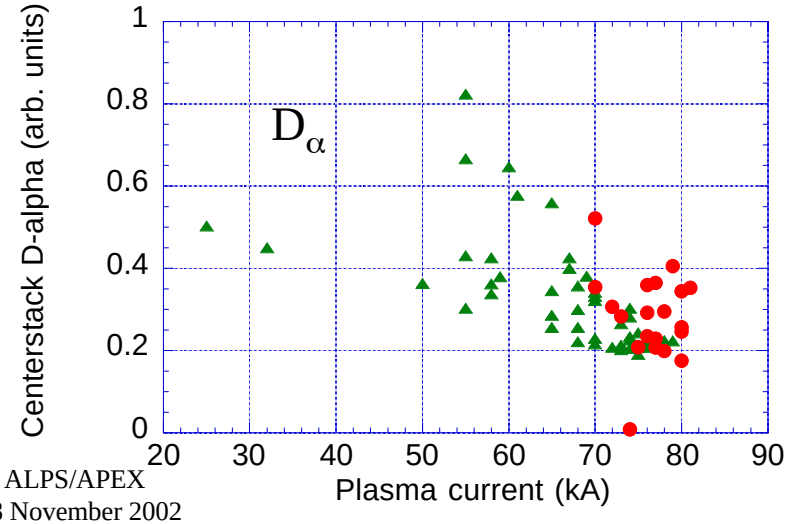


● Liquid lithium in tray (250° C)
▲ Cold lithium in tray
■ Bare stainless steel tray

Performance enhancement is primarily due to interaction with liquid lithium in the tray

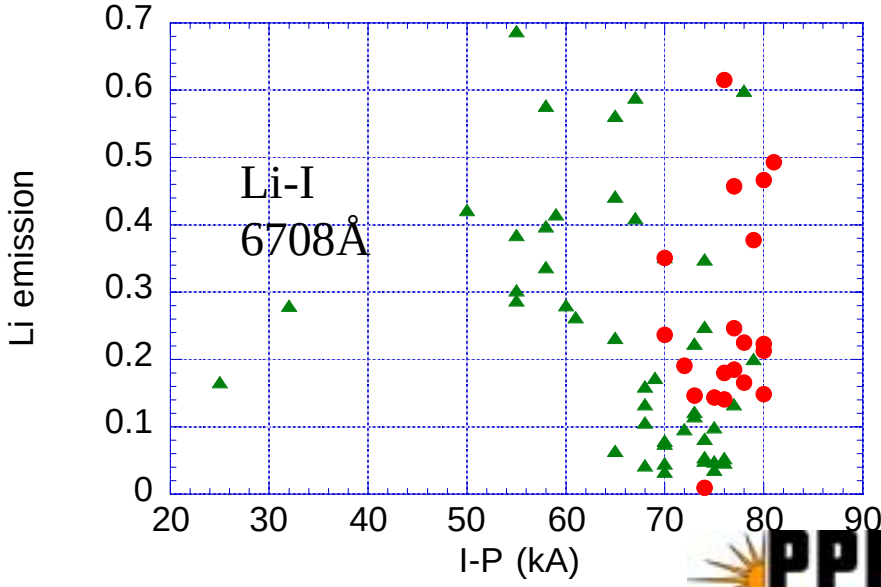
Data from the ORNL centerstack filterscope





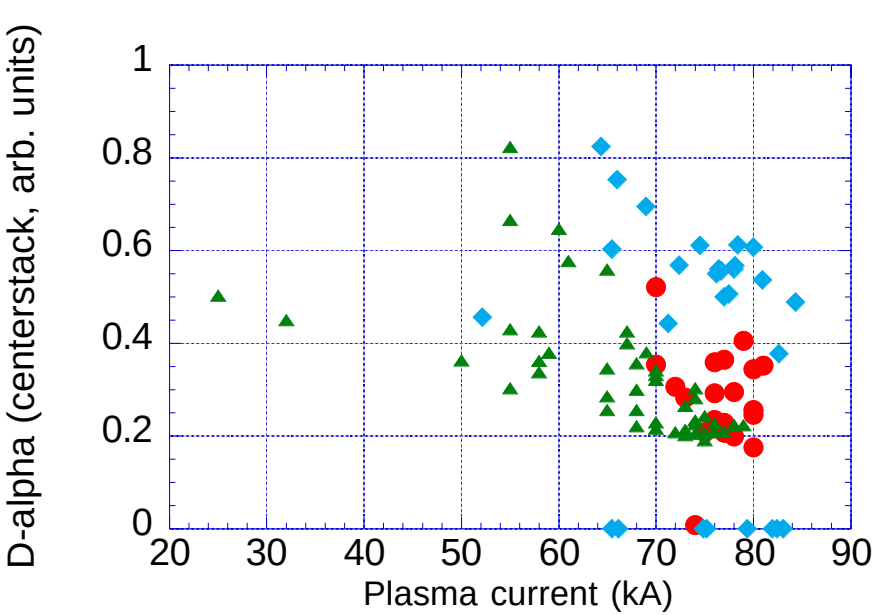
- Highest performance also correlates with lowest D_α,O centerstack light. But:
  - Liquifying the lithium does not produce a further reduction in centerstack D_α, O
  - Lithium emissions do not increase with a hot tray

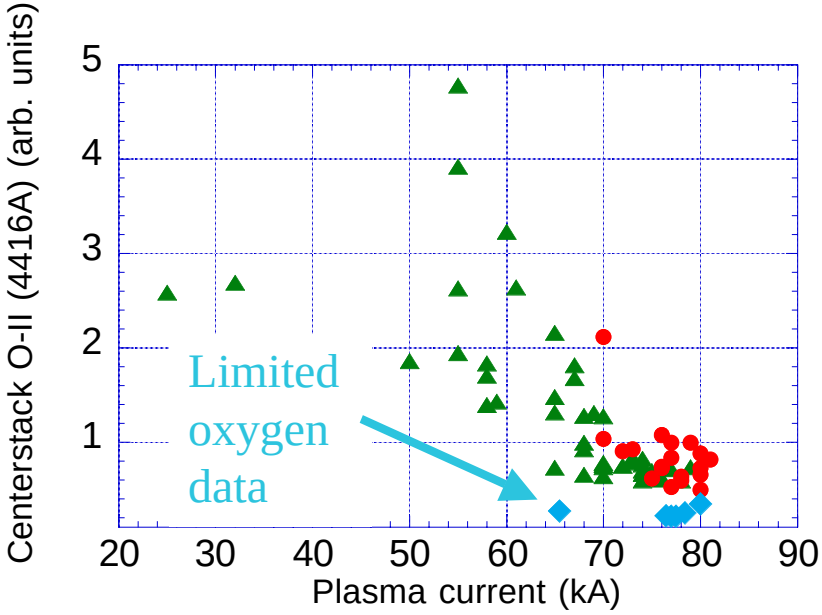
● Liquid lithium in tray (250° C)
▲ Cold lithium in tray



Vessel interior was coated with lithium during Dec 01 Recycling, impurity results compared with tray data

- Spectroscopy of edge plasma visible light emission at the centerstack indicates that cold, solid lithium coatings saturate in CDX
  - Do not reduce recycling during a discharge
- Cold coating does strongly reduce oxygen in discharge



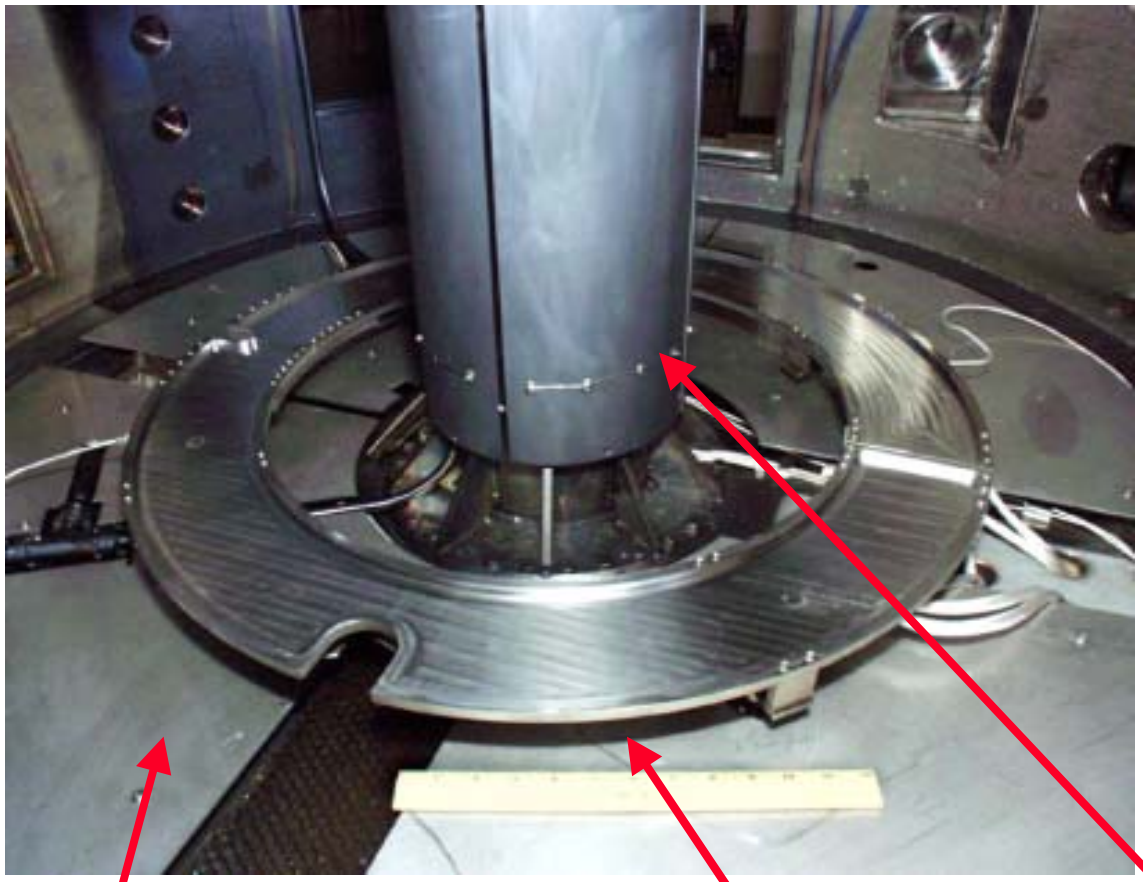


● Centerstack emission with hot tray

▲ Centerstack emission with cold tray

◆ Centerstack emission with coated centerstack (cold tray)

Report on the cleanup
Original layout of CDX-U lithium tray limiter



- Discharges run on bare SS tray to establish baseline prior to lithium filling

- 34 cm major radius, 10 cm wide, 0.64 cm deep

- Fabricated in two halves with a toroidal electrical break
  - -Isolated from vessel
  - -Halves connected to electrical feedthroughs

- Heaters beneath for temperature control up to 400^{o}C. Typ. ops 200 - 250^{o}C
- Heat shield on center stack

- Heat/lithium shield between tray and lower vacuum flange

- Tray temperature monitored with thermocouples around edge

CDX-U vented for tray cleaning

After vent but before cleaning

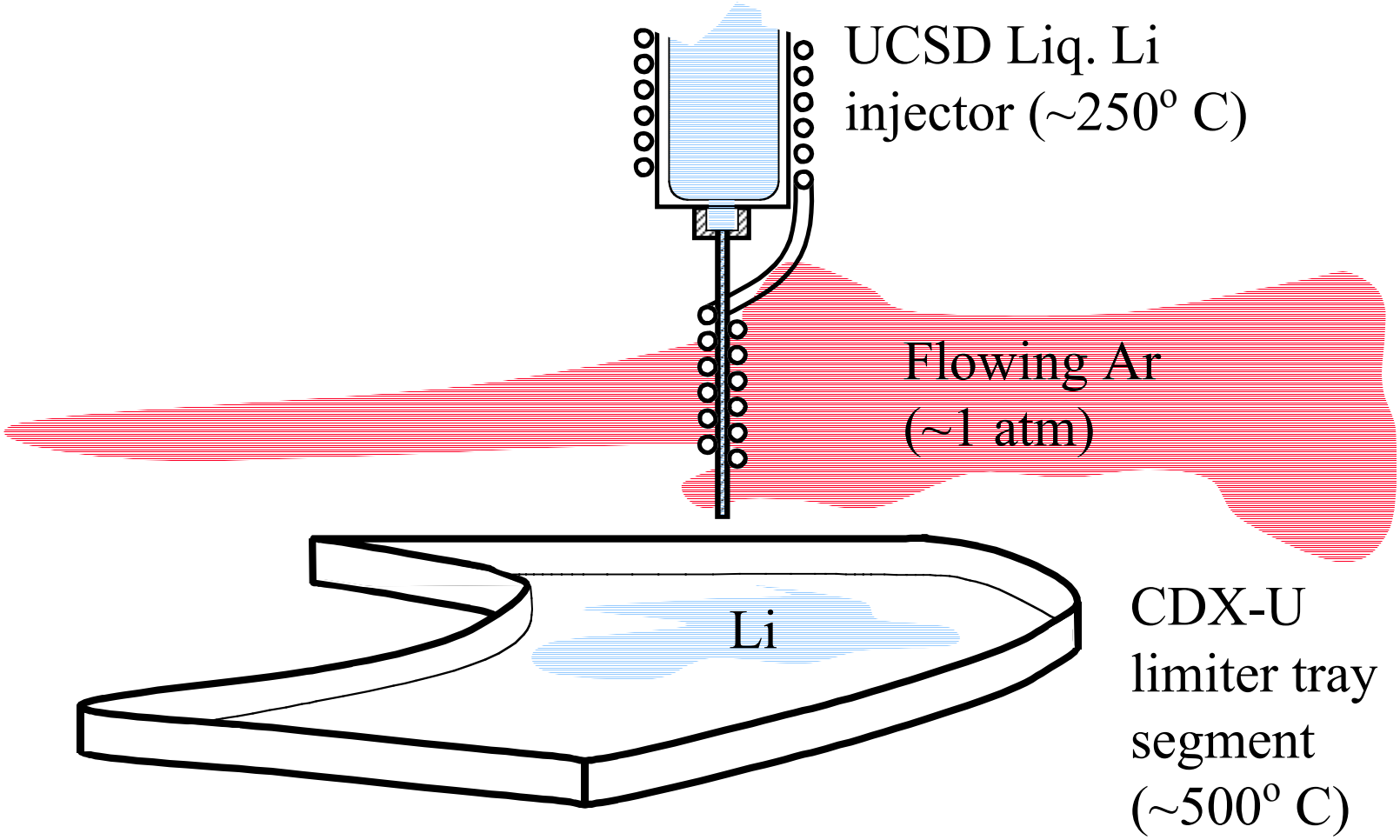
After cleaning

- Air circulated through vacuum vessel for several days
- Lithium hydroxide distribution indicates lithium covered most of tray
- Difficulty in removing coating on parts of tray suggests reaction between lithium and stainless steel
  - Flakes found in vacuum vessel appear to be stainless steel according to SEM analysis
  - Discoloration of tray sections evident after cleaning
    - » Stainless steel may thus not be ideal for long-term use with liquid lithium at T>300C

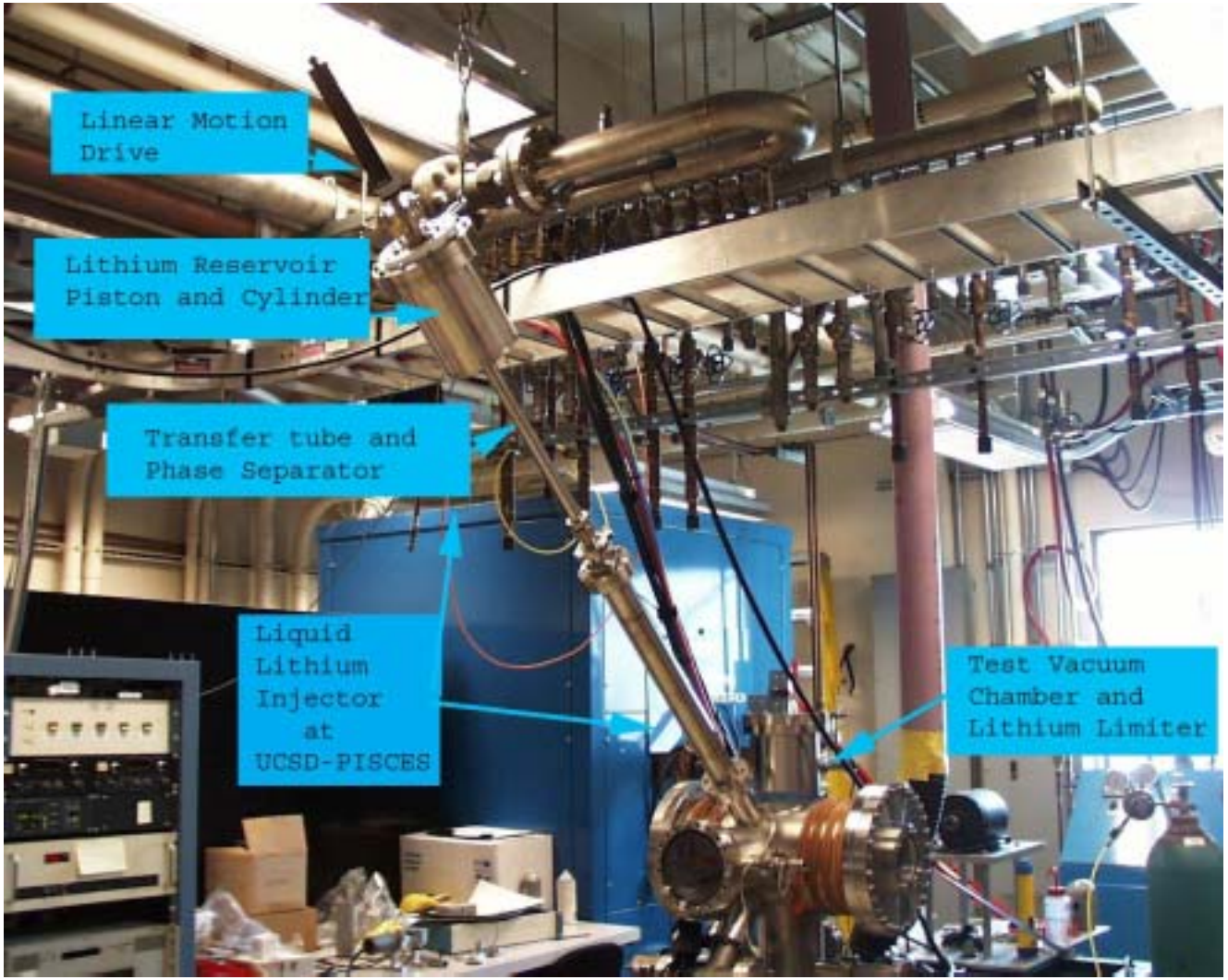
Next step is to achieve more uniform lithium layer in tray by filling with liquid instead of solid lithium

- Difficult to remove impurity layer on solid lithium pieces
- Flow over tray surface will improve with liquid lithium
- Liquid lithium still requires special conditions
  - Fill must be performed under flowing argon atmosphere
    - » Minimize lithium hydroxide formation
    - » Inhibit window, vessel coatings
  - Tray temperature must be kept above 500 degrees C
    - » Could be needed to prevent coating formation by keeping above lithium hydroxide melting point (472 degrees C)
    - » Dissolved lithium hydroxide may act as “flux” to clean tray surface for improved liquid lithium “wetting”

Schematic of UCSD liquid lithium injector concept



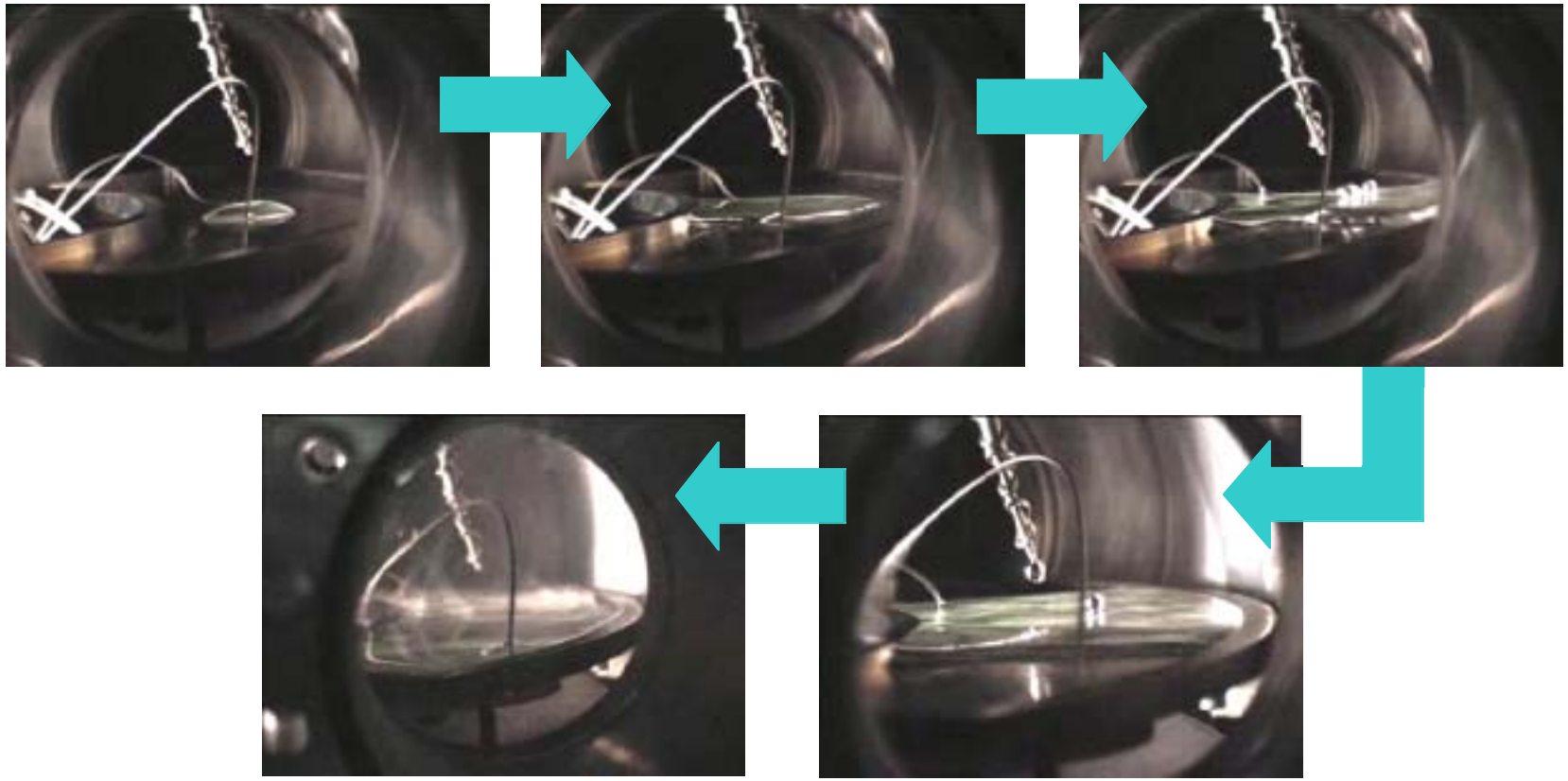
Liquid lithium injector on test chamber in PISCES laboratory at UCSD



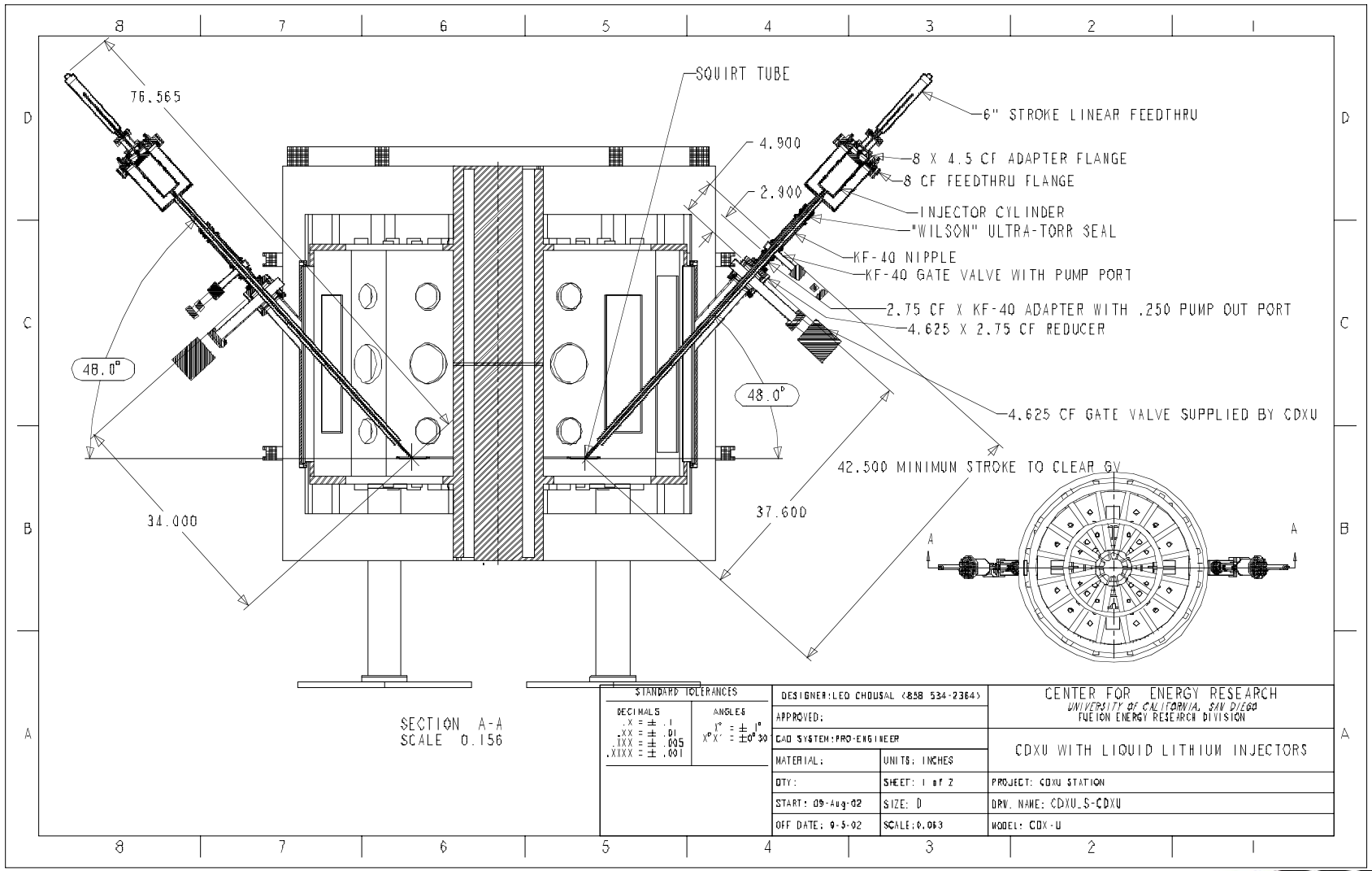
Liquid lithium filling technique demonstrated with mockup of CDX-U limiter tray

- Mockup has one-fourth of total area of CDX-U limiter tray
  - View from below shows heaters identical to those used in CDX-U tray
- Position of mockup in test chamber at UCSD
  - CDX-U tray and mockup both made of stainless steel

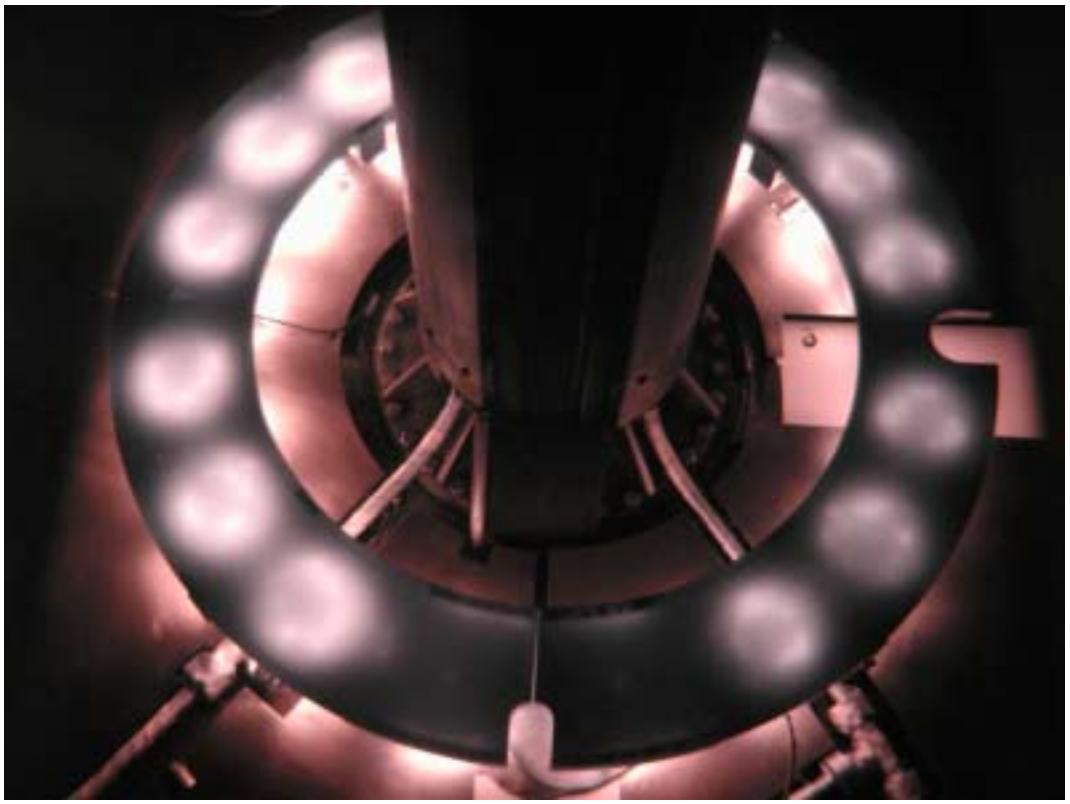
Liquid lithium spreads across surface of CDX-U limiter tray mockup



Liquid lithium will be injected into both halves of toroidal limiter tray from two locations on CDX-U

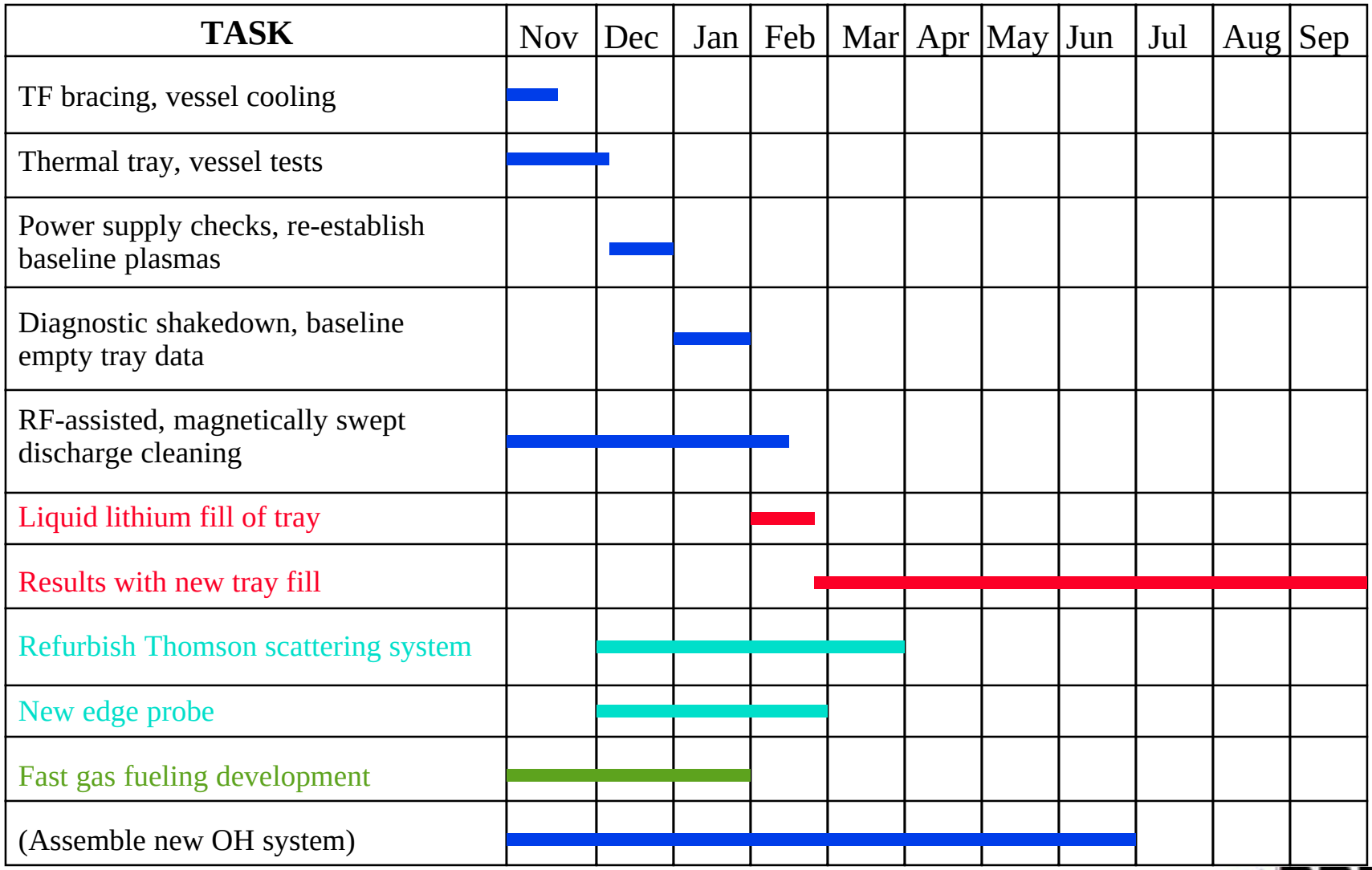


Limiter tray heaters undergoing high temperature tests in CDX-U



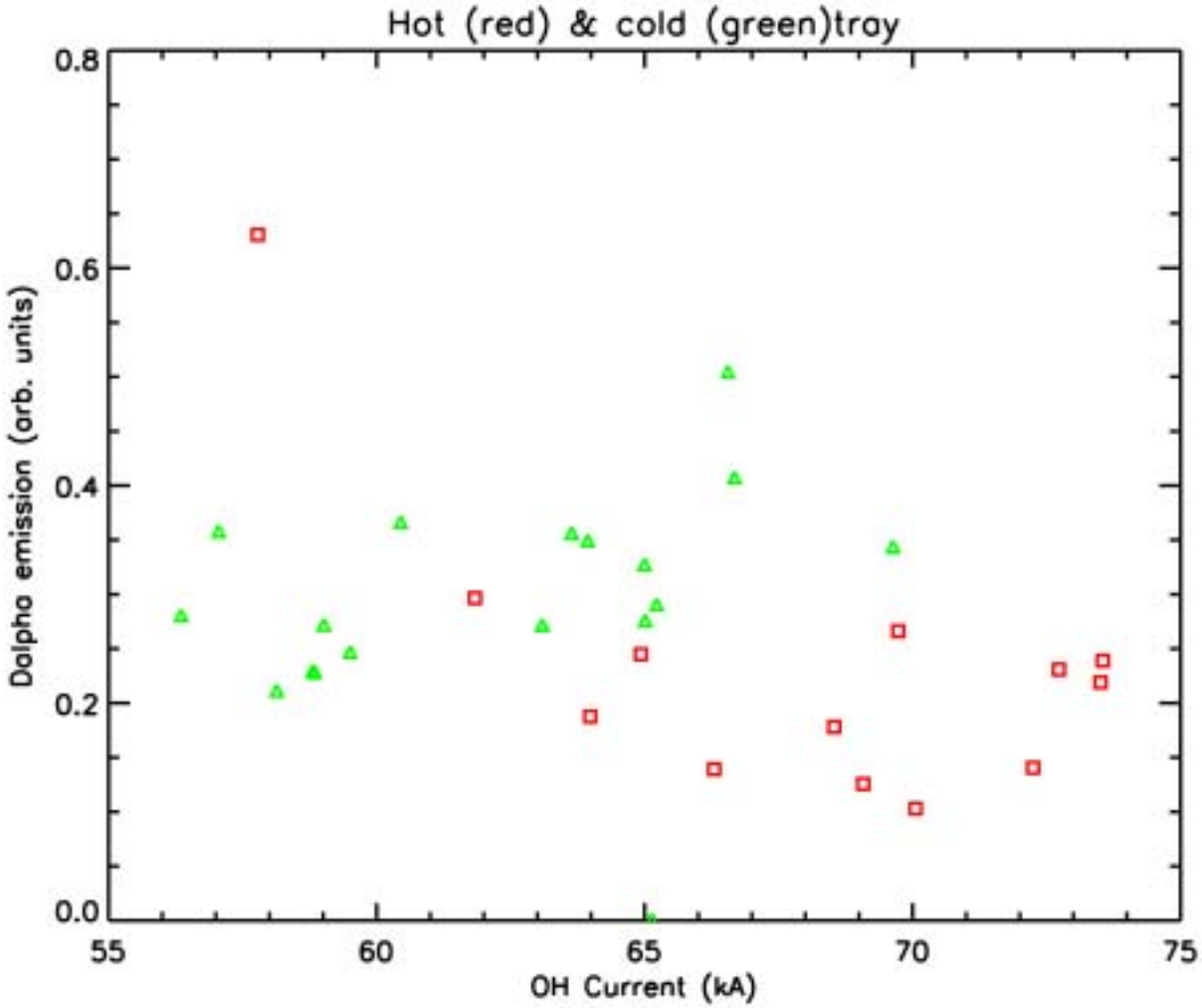
- View of limiter tray through window on top of CDX-U
  - Glowing regions indicate locations of circular heating elements at tray temperature exceeding 500 degrees C
  - Care is required to limit lithium evaporation on hot spots

Plans for FY03



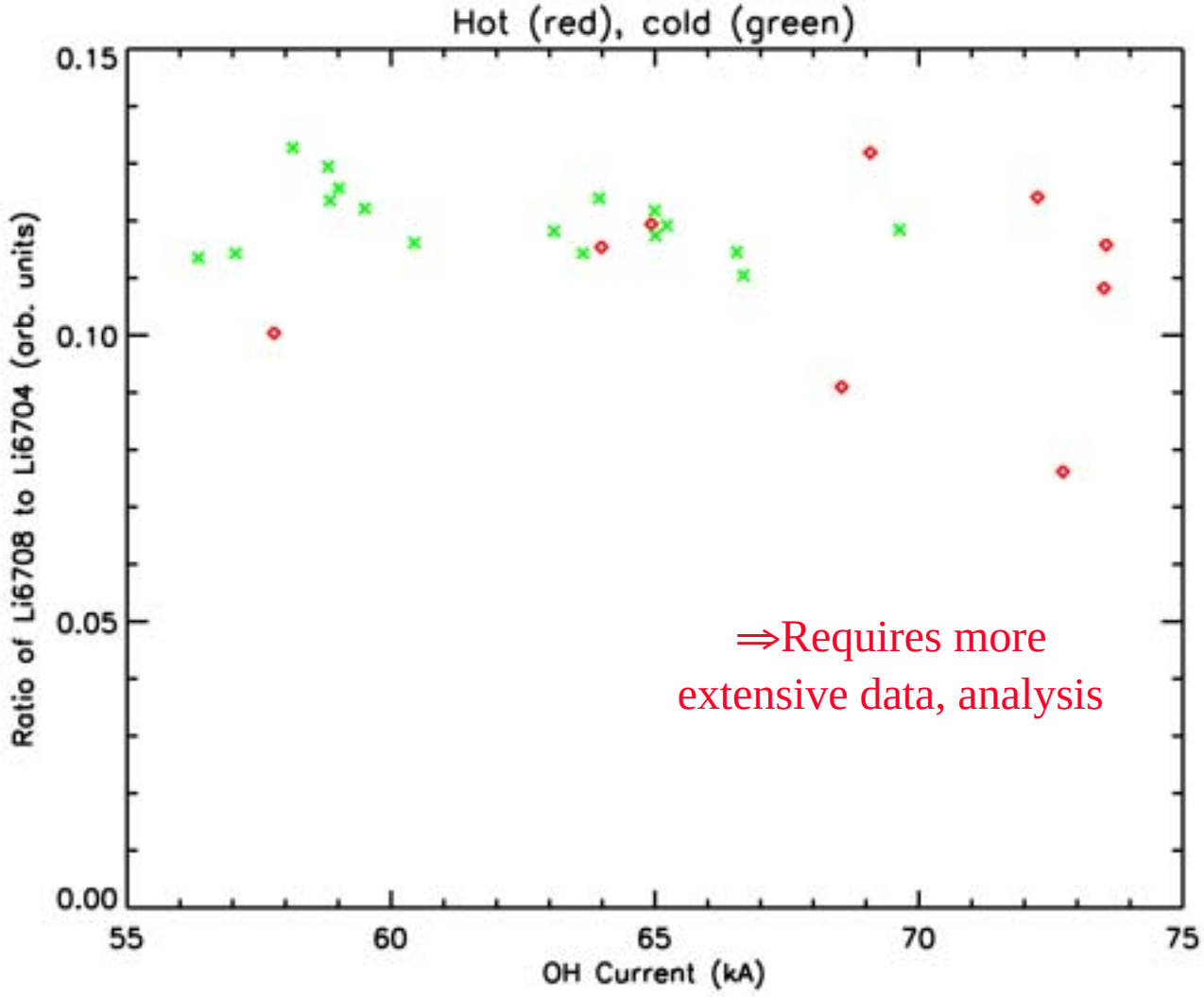
Reduction in tray D_α during tokamak operation with liquid lithium is still being observed

- Data taken 4/11/02 (hot) and 4/12/02 (cold)
  - Following overnight argon glow (original data followed 24 hour glow)



New spectroscopy indicates no evidence for an increase in edge T_e local to the tray

- Lithium 6708/6704 line ratio is sensitive to the electron temperature.



⇒Requires more extensive data, analysis